Evaluation of Commercially Available Fluid-Warming Devices for Use in Forward Surgical and Combat Areas

Guarantor: Michael A. Dubick, PhD
Contributors: Michael A. Dubick, PhD; Daniel E. Brooks, BS; Joseph M. Macaitis, BS; Terry G. Bice, BS; Aimee R. Moreau, MS; COL John B. Holcomb, MC USA

The fluid-warming capabilities of four individual fluid warmers, i.e., Level 1, FMS 2000, Thermal Angel, and Ranger, were compared to evaluate their potential for medical use in forward military echelons of care. Lactated Ringer's solution (LR) and Hextend at room temperature (20°C) or refrigerated temperature (4–7°C) and packed red blood cells at 4°C to 7°C were used with each warmer at two different flow rates. The FMS 2000 consistently warmed all fluids to approximately 37°C, regardless of the starting temperature or flow rate. The Level 1 and Ranger also efficiently warmed all fluids except cold LR to approximately 37°C. The Thermal Angel generally warmed room temperature fluid, cold Hextend, and packed red blood cells to at least 33°C to 34°C but could not warm cold LR. The clinical standard is to have fluids warmed to 32°C at a minimum and more preferably to 34°C to 35°C. Of the fluid warmers tested, only the Thermal Angel failed to achieve such a temperature in warming cold LR. Data from the present study suggest the Ranger and FMS 2000 to be operationally adaptable to at least echelons 1 and 2, respectively, whereas far-forward use of the Thermal Angel has limitations.

Introduction

Accidental or uncontrolled hypothermia is a well-recognized problem among trauma patients, requiring immediate clinical intervention.[1,2] It has been reported that up to 60% of patients admitted to regional trauma centers are hypothermic,[3] defined as having a core body temperature of <35°C.[2,4] However, the poor prognosis associated with the presence of hypothermia among trauma patients has led to the suggestion of a separate classification in which mild hypothermia includes core body temperatures of 34°C to 36°C.[2,4] Recently, Gentilello et al.[5] reported that hypothermia among trauma patients increases resuscitation fluid requirements and is an independent risk factor for acute death. Hypothermia has also been associated with prolonged clotting times and other dysfunctions of the hemostatic process, independent of the development of acidosis after traumatic injury.[4,6,7] In addition, core body temperatures of below 33°C can lead to supraventricular arrhythmias, and temperatures below 28°C increase the risk for ventricular fibrillation.[8] As a consequence, core body temperatures of 32°C or less are associated with mortality rates that approach 100%.[9]

Therefore, efforts to rewarm hypothermic patients in a timely manner are very important. Currently, means of rewarming involve either external or internal warming of the patient. External warming usually involves the use of heating lamps, circulating warm air, or heating blankets, but these techniques have not been very effective for rewarming severely hypothermic patients in a timely manner.[10] For internal core rewarming, infusion of warmed fluids via cardiopulmonary bypass and continuous arteriovenous rewarming are considered the most efficient means of warming hypothermic patients, whereas infusion of warmed intravenous fluids may be the most cost effective,[4,5,10,11] particularly when the patient requires large volumes of fluid.

Problems with the development of satisfactory fluid warmers are related to local overheating, leading to hemolysis of heated blood,[12] or the inability to deliver fluid at <750 mL/hour at what would be considered "therapeutic temperatures," because of cooling within the tubing.[10,13] Because it is well recognized that infusion of large volumes of unheated fluid contributes to hypothermia among trauma patients,[7,14,15] efforts to develop the most efficient fluid-warming devices continue. The Level 1 fluid warmer (Level 1 Technologies, Marshall, Massachusetts) has received acceptance for use in trauma centers[14] because it can be set up and primed easily and its use has been shown to maintain and even increase core temperatures.

The military operates in all climates and all elements. With both battle and nonbattle injuries, treatment of injured soldiers in adverse environments and delayed evacuation make them prone to develop uncontrolled or accidental hypothermia. Many of these casualties may require fluid resuscitation or irrigation of wounds. As reported by Garcia et al.,[7] forward-deployed medical units do not have the capability to warm large volumes of intravenous fluids adequately, although meal ready to eat flameless heaters have been used. A fluid warmer suitable for military use at forward echelons of care must be rugged, easy to use under austere conditions, easy to transport, light in weight, and small in size and must have minimal power requirements. To improve the treatment of injured soldiers in forward areas, the Army would like to field the operationally most relevant and best performing fluid warmer available. Using state-of-the-art technology to treat injured soldiers will preserve and stabilize the Objective Force. Therefore, the objectives of this study were to evaluate the fluid-warming capabilities of both portable and floor model fluid-warming devices that could be adapted to forward treatment areas.

Materials and Methods

This study compared four fluid-warming systems. The Level 1 Model 1000 (Level 1 Technologies) and FMS 2000 (Belmont Instruments, Billerica, Massachusetts) systems were compared as floor units, whereas the Thermal Angel (Estill Medical Technologies, Dallas, Texas) and Ranger (Arizant Heathcare, Eden

U.S. Army Institute of Surgical Research, Fort Sam Houston, TX 78234.

The opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

This manuscript was received for review in April 2003 and was accepted for publication in June 2003.

Reprint & Copyright © by Association of Military Surgeons of U.S., 2005.

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302 Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
01 JAN 2005	**N/A**	**-**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Evaluation of commercially available fluid warming Devices for use in forward surgical and combat areas.	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Dubick M. A., Brooks D. E., Macaitis J. M., Bice T. G., Moreau A. R., Holcomb J. B.,	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **United States Army Institute of Surgical Research, JBSA FOrt Sam Houston, TX 78234**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT	b ABSTRACT	c THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**8**	

Prairie, Minnesota) blood/fluid-warming systems were compared as portable units. These devices are shown in Figure 1.

These instruments were evaluated with three different fluids (lactated Ringer's solution [LR], Hextend, Abbott Laboratories, Abbott Park, Illinois and packed red blood cells [PRCs]). LR was selected as the standard-of-care crystalloid available at most medical facilities; Hextend (6% hetastarch in a balanced salt solution) is carried in the field by Special Forces medics. Also, it was reported that far-forward Special Forces medics recently carried PRCs in Afghanistan. Therefore, these three fluids could be used at all echelons of care.

LR and Hextend at two temperatures, i.e., room temperature (20°C) and refrigerated (4–7°C), and refrigerated PRCs were used with each warming device at two flow rates. The Thermal Angel and Ranger were evaluated at flows rates achieved with a pressure bag set at the 150 and 300 mm Hg settings and flow through an 18-gauge catheter. Flow rates for the FMS 2000 were evaluated at settings of 150 and 300 mL/minute. After it was determined that rates above 250 mL/minute were difficult to achieve under the conditions of this study, the warming capabilities of the FMS 2000 were evaluated at 150 and 250 mL/minute. The Level 1 system was evaluated at its single pressure setting, which corresponds to approximately 220 to 300 mm Hg. Again, flow was determined through an 18-gauge catheter. Each test was performed in triplicate.

The instruments were set up and temperature probes were placed in the fluid bag and at the end of the instrument's outflow catheter, which would be attached to the patient. Except for the Thermal Angel, temperature probes were also placed 5 inches (12.7 cm) from the inflow to the warmer and 5 inches (12.7 cm) from the outflow port of the warmer. For the Thermal Angel, these probes were placed at 7 inches (17.8 cm) and 3.5 inches (8.9 cm), respectively. These differences in locations of the temperature probes reflect the sites of the injection ports for the infusion sets used with each device. The temperature probe placed at the end of the catheter corresponded to 49 inches (124.5 cm) for the Ranger, 10.5 inches (26.7 cm) for the Thermal Angel, 79 inches (200.7 cm) for the Level 1, and 58 inches (147.3 cm) for the FMS 2000 from the outflow port of each unit. At each fluid temperature and flow rate, the instrument being tested was turned on and allowed to warm up according to the manufacturer's recommendations. Each run proceeded until the fluid bag was empty, and temperature data were recorded continuously.

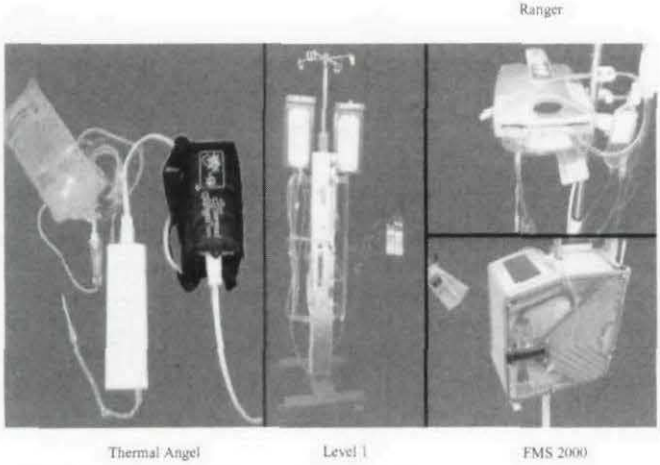

Fig. 1. The four fluid-warming devices evaluated.

Of primary interest were the time to set up the instrument, the steady temperature achieved, the time for the instrument to reach a steady temperature (warm-up time), the prime volume, the time for room temperature or refrigerated fluids to reach a steady temperature, and the temperature difference between the starting temperature and the warmed fluid temperature. We also determined the percentage of time the temperature readings were ≥32°C or ≥35°C at each flow rate. At a minimum, the fluid warmer should be able to heat fluid at room temperature to the clinically acceptable minimal infusion temperature of 32°C.[16] Because many think that 32°C is too low as an acceptable standard for trauma patients,[2,4] we also evaluated 35°C as a standard. Of secondary interest were the ease of operation, the weight and size of the instrument, and the bubble-suppressing ability of the device. To determine the ease of operation, we invited a Special Forces medic and a registered nurse who were unfamiliar with the devices to set up each fluid warmer. We also evaluated the set-up times after they had performed this operation once.

As appropriate, data were analyzed with analysis of variance. If a significant difference was detected, then post hoc tests (e.g., Tukey's honestly significantly different test) were used to determine differences among the instruments measured at the outlet port and catheter tip; $p < 0.05$ was considered statistically significant, after correction for multiple comparisons.

Results

Table I compares the weight, size, power requirements, and cost of the four fluid warmers evaluated. As can be seen, the weight advantage of the Thermal Angel is lost when the battery pack is carried. Although the combined weight becomes nearly equivalent to that of the Ranger, the Ranger still requires an external power source. In comparison to the Level 1, the FMS 2000 is more compact in size and the weight includes the built-in pump (Table I). In addition, the Ranger and Level 1 systems have a bubble trap, whereas the FMS 2000 has an air detector, will degas fluid, and, unlike the other units evaluated, will not pump air.

Table II compares the temperature set points, flow rate ranges, warm-up times, and priming volumes of the fluid warmers. In general, at each set flow rate, flow rates for normal saline were higher than those for Hextend with all fluid warmers (Fig. 2). At the higher set flow rate, actual flow rates achieved through the 18-gauge catheter for normal saline and Hextend were significantly higher with the Ranger and FMS 2000 than with the Thermal Angel. This was also observed at the lower set flow rate with respect to Hextend (Fig. 2). It should be noted that, although the higher flow rate for the FMS 2000 was set at 300 mL/minute, this flow rate was not achieved for either fluid because of built-in pressure sensors in the unit reducing the flow to be compatible with maximal flows through an 18-gauge catheter (Fig. 2).

Warm-up times varied among the fluid warmers. The FMS 2000 required only approximately 15 s, whereas the Level 1 system required more than 4 minutes for a water bath to heat. Table II shows the warm-up times for the different fluid warm-

TABLE I

PHYSICAL CHARACTERISTICS

	Thermal Angel	Ranger	Level 1 Model 1000	FMS 2000
Mass, lb (kg)	0.56 (0.26); battery, 6.65 (3.0)	7.44 (3.4)	20 (9.5); 64 (29.1)	26 (11.8)
Dimensions				
Inches (cm) (L × W × H)	9 × 2.75 × 1 (23 × 7 × 2.5)	10 × 7.5 × 4.5 (25 × 19 × 11)	48 × 13 × 10 (120 × 32 × 25)	13.5 × 7.5 × 12 (34.3 × 19 × 30.5)
Cubic inches	24.8	337.5	6240	1215
Cubic feet	0.014	0.2	3.6	0.7
Power				
Requirements	12 V battery	100–120 V, 50/60 Hz; 220–240 V, 50 Hz; 900 W	110 V, 50/60 Hz	115 V, 50–400 Hz; 220–240 V
Battery	Yes	No	No	Yes
AC	No	Yes	Yes	Yes
Battery recharge time	14 h	—	—	8 h
Unit cost ($)	125	1,450	5,100	19,900
Infusion set cost ($)	1.5	45	28	100

AC, alternating current.

TABLE II

FLUID WARMER THERMAL CHARACTERISTICS

	Thermal Angel	Ranger	Level 1 Model 1000	FMS 2000
Temperature set point	38°C	41°C	41.7 ± 0.3°C	37.5°C (50–500 mL/min), 39°C (10–50 mL/min)
Over-temperature alarm	—	43°C	44.9 ± 0.1°C	42°C
Under-temperature alarm	—	33°C	—	—
Over-temperature cut-off	—	46°C	—	—
Flow rates (mL/min)	2–150	100–500 (high flow set)	40–500	10–500, 2.5 and 5 (no heat)
Warm-up time	45 s	<2 min	4–8 min	15 s
Priming volume (mL)	25	120	56	230

ers, as well as the priming volumes. Once each instrument warmed up, it took less than 50 s to reach a steady temperature at the outlet port.

At both flow rates evaluated, the FMS 2000 and Ranger warmed room temperature LR to at least 37°C at the outlet port, whereas this fluid was warmed to only 35.4°C or less by the Thermal Angel (Fig. 3). At the low flow rate setting, the Ranger and FMS 2000 warmed refrigerated LR, Hextend, and PRCs to at least 36°C (Fig. 3). Although at this flow rate the Thermal Angel warmed cold Hextend and PRCs to >33°C, it could warm cold LR to only 27.3°C (Fig. 3). At the high flow rate, all four fluid warmers warmed cold Hextend and PRCs to at least 35°C (Fig. 3), whereas the Thermal Angel and Level 1 did not warm cold LR above 35°C (Fig. 3). Also, at each flow rate, the fluid temperatures achieved at the outlet port were only slightly less than those measured at the catheter tip (data not shown).

The time for each fluid to reach or exceed the average warmed temperature at the outlet port at each flow rate is depicted in Table III. This temperature generally occurred earliest with the FMS 2000, which suggests that this device was able to warm fluid to a more consistent temperature than were the other systems. The longer times for a particular fluid warmer to reach this average temperature suggested more variation in the temperatures achieved. At the high flow rate, the Thermal Angel took longer to warm cold fluid to its average temperature than did the other fluid warmers, but this observation was not consistent at the low flow rate (Table III). Greater variation in the temperatures achieved by the Thermal Angel, for example, was confirmed by statistically analyzing the fluctuations in average temperatures (data not shown).

The change in temperature from the inlet port to the outlet port was used as an index of the warming ability of each fluid warmer. As shown in Table III, this temperature differential was generally less for cold fluid warmed by the Thermal Angel, compared with the other units.

From a practical standpoint, data were analyzed to determine the proportion of time that one of the devices would be able to warm fluid to at least 32°C and 35°C. Figure 4 depicts the percentage of time that a fluid warmer maintained the fluid temperature at ≥32°C, as measured at the outlet port, at each flow rate. As indicated, at the low flow rate, the Ranger and FMS 2000 were able to maintain this temperature 100% of the time, whereas this was not the case for the Thermal Angel. Based on the temperature achieved in warming cold LR, the Thermal Angel reached 32°C only 5.1% of the time. A similar pattern of temperature achievement for these three fluid warmers was observed at the high flow rates, whereas the Level 1 was also able to achieve 32°C 100% of the time (Fig. 4). Analysis of the time that the temperature measured at the catheter tip remained at ≥32°C showed a trend similar to that for the temperature measured at the outlet port (data not shown).

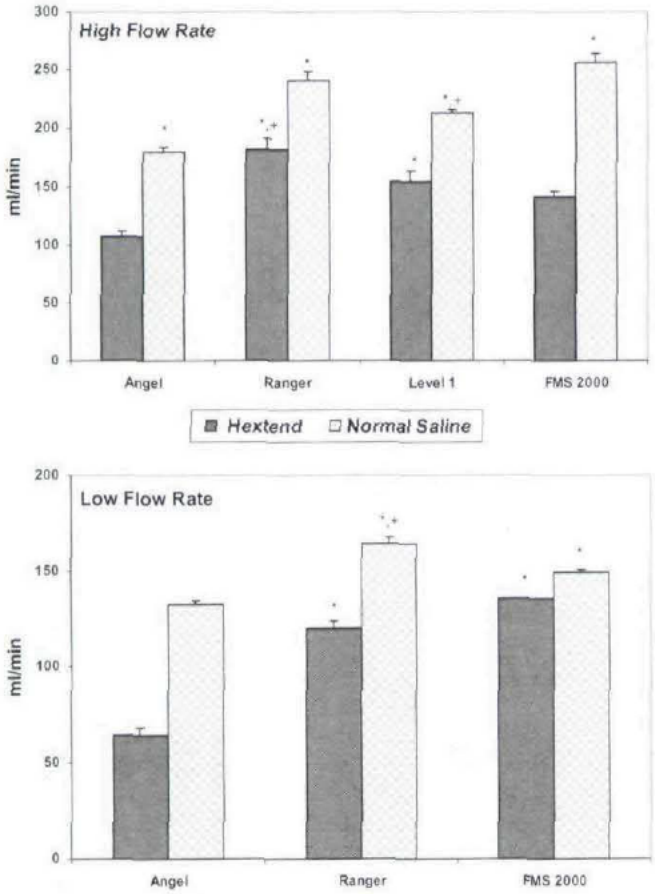

Fig. 2. Flow rates achieved for normal saline solution or Hextend through an 18-gauge catheter. See "Materials and Methods" for definition of high and low flow rates. Data represent mean ± SEM (n = 3/group). *, $p < 0.05$ from Thermal Angel; +, $p < 0.05$ from FMS 2000.

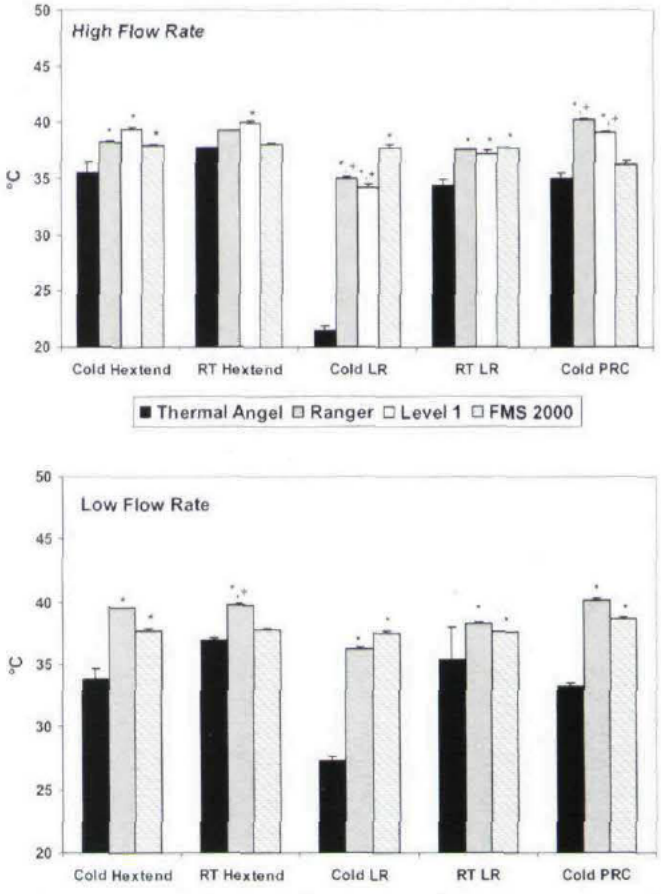

Fig. 3. Average temperature of each fluid achieved at the outlet port at each set flow rate. Data represent mean ± SEM (n = 3/group). RT, room temperature. *, $p < 0.05$ from Thermal Angel; +, $p < 0.05$ from FMS 2000.

The time each fluid warmer was able to maintain the fluid temperature at ≥35°C, as measured at the outlet port, is depicted in Figure 5. Of note, with cold LR at the high flow rate, 35°C was not achieved with the Thermal Angel, whereas the Ranger and Level 1 maintained this temperature 51.6% and 19.6% of the time, respectively. As before, a similar pattern of maintaining temperature was observed at the catheter tip (data not shown).

In the evaluation of the time required to set up each fluid warmer, as shown in Table IV, the Special Forces medic required 3 to 5 minutes to set up a fluid warmer. This individual took an additional 2 minutes to set up the FMS 2000, compared with the other fluid warmers, but dramatically reduced the set-up time for the FMS 2000 and Level 1 after the first attempt. In contrast, the registered nurse had difficulty setting up the Level 1 fluid warmer on the first try, while also needing 3 to 5 minutes to set up the other units (Table IV). This individual also showed much improvement in set-up times, especially with the Level 1, after the first try.

Discussion

Basically two different types of fluid warmers were evaluated in this study. The Thermal Angel and Ranger were evaluated as portable devices that could have application in prehospital settings or even in far-forward military environments, whereas the Level 1 and FMS 2000 fluid warmers are designed to be attached to intravenous infusion poles and were evaluated for hospital use. The latter units are substantially heavier than either the Thermal Angel or Ranger; they also require an external power source, although the FMS 2000 has a battery back-up system that allows it to pump fluid (unheated). Nevertheless, the Level 1 and FMS 2000 are suitable for Department of Defense forward surgical units, such as an expeditionary medical support system, forward resuscitative surgical system, forward surgical team, or combat support hospital, although the FMS 2000 is compact and self-contained and may be adaptable for use in aircraft or more-forward sites where power is available. To our knowledge, however, this use has not been explored in a systematic manner. Both of these fluid warmers have been described in recent publications.[13,17-19]

The Thermal Angel may be best suited for use in the most-forward echelons of care, because it is lightweight and battery operated, although the battery itself is heavy. It is also disposable and has no additional parts requirement, other than an infusion set. The Ranger, however, requires an external energy source and a fluid cassette that slides into the warming device. This cassette is then attached to the fluid source. As shown by the data in the present study, the Ranger was the more efficient fluid warmer of the two devices, at both flow rates and with all fluids, especially with cold LR. This may result in part from the

TABLE III

WARMING EFFECTIVENESS OF EACH DEVICE AT EACH FLOW RATE

	Cold Hextend	RT Hextend	Cold LR	RT LR	Cold PRCs
High flow					
Time to reach average temperature at outlet (s)					
Thermal Angel	327 ± 3	93 ± 3	320 ± 6	287 ± 17.6	210 ± 150
Ranger	157 ± 8.8[a]	147 ± 3	173 ± 18[a]	177 ± 18	110 ± 21
Level 1	227 ± 12	217 ± 3[a,b]	247 ± 20[b]	93 ± 28[a]	90 ± 15
FMS 2000	110 ± 10[a]	77 ± 3	80 ± 15	60 ± 0[a]	83 ± 7[a]
Change in temperature from inlet to outlet port (°C)					
Thermal Angel	28.9 ± 0.6	14.8 ± 0.1	15.8 ± 0.3	13.9 ± 0.4	24 ± 0.5
Ranger	30.7 ± 1	18.4 ± 0.03	28.7 ± 3.3[a]	17.1 ± 0.06	31.4 ± 1.4[a]
Level 1	32.9 ± 1.5	19.3 ± 0.4	29.7 ± 0.2[a]	16.7 ± 0.3	33.6 ± 0.1[a]
FMS 2000	31.3 ± 0.5	14.6 ± 0.1	32.1 ± 0.3[a]	16.3 ± 0.01	27.5 ± 1.9
Low flow					
Time to reach average temperature at outlet (s)					
Thermal Angel	90 ± 17	67 ± 7	337 ± 26	163 ± 71	77 ± 17
Ranger	143 ± 42	170 ± 2	213 ± 33[a,b]	173 ± 33	103 ± 12
FMS 2000	107 ± 3	83 ± 3	73 ± 9	97 ± 14.5	93 ± 12
Change in temperature from inlet to outlet port (°C)					
Thermal Angel	26.5 ± 0.7	15.4 ± 0.3	20.3 ± 0.5	14.8 ± 2.7	22.5 ± 1
Ranger	33.3 ± 0.3[a]	17.3 ± 0.03	31.1 ± 0.4[a]	18 ± 0.1	34.2 ± 0.1[a]
FMS 2000	31.6 ± 0.3[a]	14.2 ± 0.4	31.3 ± 0.8[a]	16.4 ± 0.1	30.4 ± 1.2[a]

Data are expressed as mean ± SE ($N = 3$). RT, room temperature.

[a] $p < 0.05$ from Thermal Angel.

[b] $p < 0.05$ from FMS 2000.

Ranger having a higher set temperature than the Thermal Angel (41°C and 38°C, respectively). Another important factor that likely influenced this outcome was the fact that the use of a pressure bag set to 300 mm Hg induced flow rates for standard crystalloid fluids (such as normal saline solution or LR) that were higher than the maximal flow rate stated by the manufacturer for the Thermal Angel. Even the flow rate that resulted from the pressure bag being inflated to 150 mm Hg approached this upper limit. The Thermal Angel warmed Hextend better than LR, which might reflect the higher viscosity of Hextend, in comparison with normal saline or LR. Consequently, the flow rates for Hextend fell within the range reported by the manufacturer for the Thermal Angel. Again, the ability of the Thermal Angel to warm cold PRCs infused at 300 mm Hg reflects the higher viscosity of this fluid and the much lower flow rate, allowing for warming of the blood.

The results of the present study indicated that the FMS 2000 most consistently warmed fluid to ≥37°C, independent of the fluid type and flow rate, and in many cases warmed cold fluid better than the Level 1. Whereas the Level 1 relies on heating a water bath to 41°C, the FMS 2000 is designed to warm fluid to 37°C at the flow rates achieved in this study or to 39°C at low flow rates.

It should be noted that the flow rates observed in the present study were generally below those reported as maximal flow rates or even the flow rate set by the instrument. For example, the flow rates for normal saline solution and Hextend with the FMS 2000 set at 300 mL/minute never achieved this rate. This was attributed to the use of an 18-gauge catheter in the present study, and the flow rates achieved through this catheter were consistent with the flow rates for crystalloids stated by the manufacturer. This catheter size is carried in the field by medics and would be the size most likely used outside the hospital, with the availability of large volumes of fluid. The FMS 2000 has built-in pressure sensors that slow the flow rate if too high a flow is attempted for a particular fluid through a small catheter. It should be noted that, if a 16-gauge catheter is used, then maximal flow rates for the FMS 2000 increase to 400 to 500 mL/minute, depending on the fluid (e.g., blood or crystalloid, respectively).

An important goal of this study was to put the warming capabilities of these devices into clinical perspective. As described by Russell,[16] 32°C was selected as the minimal acceptable infusion temperature for a massive blood transfusion. At temperatures of >32°C, the body is thought to be able to increase its temperature by shivering.[20] In a recent review of in-line fluid warmers,[21] it was decided that, at a minimum, a fluid warmer should be able to warm room temperature fluid to 32°C. This was considered the least challenging scenario for a fluid warmer. As noted in the present study, all fluid warmers evaluated essentially achieved this capability at both flow rates examined, and only the Thermal Angel failed to achieve this temperature in warming cold LR. Again, it should be emphasized that this endpoint of 32°C may be insufficient for improving outcomes among trauma patients.[4,5]

In the past decade, it has been reported that trauma patients with core temperatures of <34°C have 35% higher mortality rates than normothermic patients.[22] Therefore, we also evaluated each fluid warmer for its ability to warm fluid to ≥35°C. Anon[21] also chose 35°C as a goal for warming room temperature

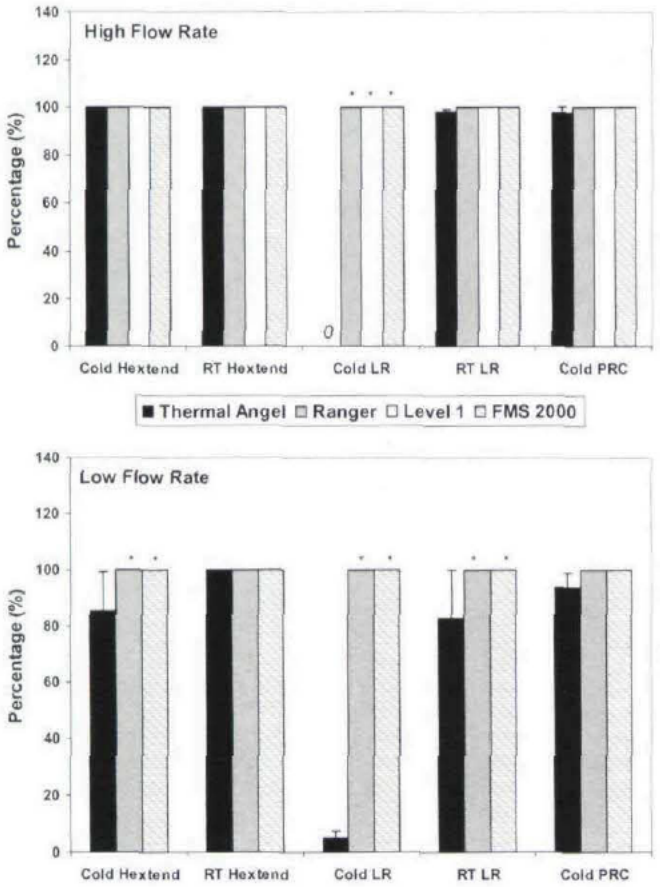

Fig. 4. Proportion of time, as a percentage, that the temperature at the outlet port was ≥32°C at each set flow rate. Data represent mean ± SEM (n = 3/group). RT, room temperature. *, $p < 0.05$ from Thermal Angel; +, $p < 0.05$ from FMS 2000.

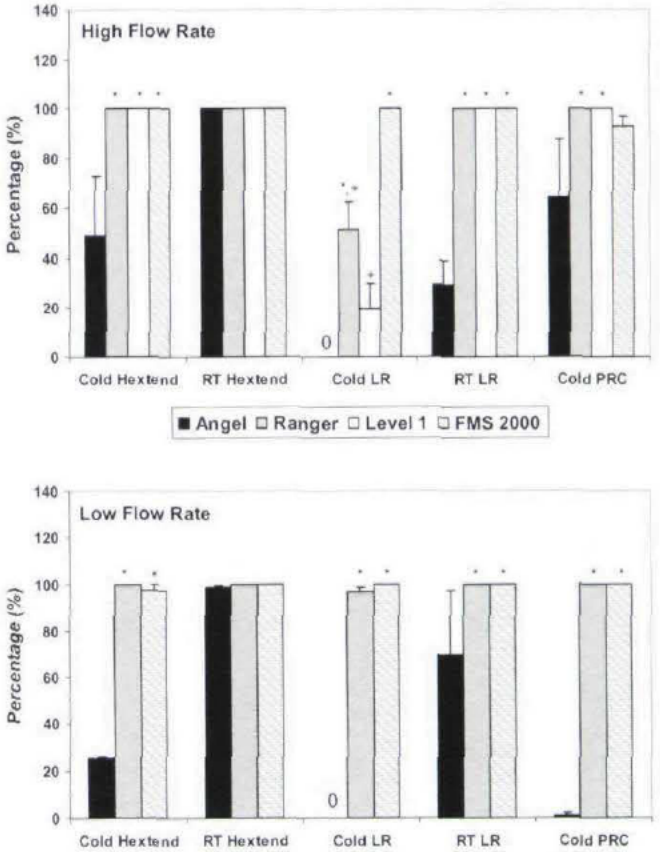

Fig. 5. Proportion of time, as a percentage, that the temperature at the outlet port was ≥35°C at each set flow rate. Data represent mean ± SEM (n = 3/group). RT, room temperature. *, $p < 0.05$ from Thermal Angel; +, $p < 0.05$ from FMS 2000.

or 10°C fluid, referring to this as a more challenging scenario for the warming device. Such a temperature would be a more desirable endpoint for warming trauma patients. As observed in the present study, the Ranger and FMS 2000 were consistently able to warm all fluids to this temperature at both flow rates. With room temperature fluid, the Thermal Angel could also achieve this temperature with all fluids; however, in warming cold fluid, particularly LR, the Thermal Angel could not achieve this temperature. At low flow rates, it also was not effective in raising the temperature of cold Hextend or PRCs. As mentioned, at high flow rates, the Thermal Angel was effective in warming PRCs to this temperature only because the flow rate was so low. It should also be mentioned that the Level 1 was not effective in achieving 35°C with cold LR.

In conclusion, the FMS 2000, the most expensive of the fluid warmers evaluated and the one with the most safety features, was the most consistent in warming the three fluids examined, at both flow rates. The more moderately priced Level 1 was limited by having only one flow rate and was not effective in warming cold LR to ≥35°C. The Ranger, as a portable unit, was also an effective fluid warmer at both flow rates. The Thermal Angel was the least expensive fluid warmer and had difficulty warming cold crystalloids. Therefore, for relatively fixed Department of Defense field medical facilities (echelon 2), the FMS 2000 is fully self-contained and would be the most efficient and versatile fluid warmer of the units examined. Of the portable units, the Ranger was clearly superior to the Thermal Angel in warming fluids of both temperatures at flow rates observed in this study and could be used in echelon 1 medical facilities, as long as power is available. However, the Thermal Angel is the most likely to be adapted for far-forward combat environments, because it is battery powered. Therefore, based on environmental conditions and the medical needs in the situation, the user must be aware of the limitations of the Thermal Angel in warming refrigerated fluids and must determine whether infusing only partially warmed fluids would be less detrimental than

TABLE IV

SET-UP TIMES

	Set-Up Times (min)	
	No Experience	With One Try
Medic		
FMS 2000	5:39	2:45
Ranger	3:39	2:44
Thermal Angel	3:10	2:18
Level 1	3:25	1:27
Registered nurse		
FMS 2000	4:05	2:48
Ranger	4:58	3:21
Thermal Angel	3:14	2:27
Level 1	8:13[a]	3:05

[a] Reflects 3 to 4 minutes trying to remove an air bubble.

infusing cold fluid or must limit the amount of cold fluid being infused. Additional studies of the capabilities and limitations of each warming device under military-relevant conditions will allow more effective use and improve fluid resuscitation of injured soldiers.

Acknowledgments

We are grateful to Dr. George Herzlinger for the loan of the FMS 2000 and we appreciate the assistance of Michael Beaulieu in obtaining the Thermal Angel and Ranger used in this evaluation. We also thank Amber Large for assistance in the preparation of this article.

References

1. Luna GK, Maier RV, Pavlin EG, Anardi D, Copass MK, Oreskovich MR: Incidence and effect of hypothermia in seriously injured patients. J Trauma 1987; 27: 1014–18.
2. Gentilello LM: Advances in the management of hypothermia. Surg Clin North Am 1995; 75: 243–56.
3. Steinmann S, Shackford SR, Davis JW: Implications of admission hypothermia in trauma patients. J Trauma 1990; 30: 200–2.
4. Peng RY, Bongard FS: Hypothermia in trauma patients. J Am Coll Surg 1999; 188: 685–96.
5. Gentilello LM, Jurkovich GJ, Stark MS, Hassantash SA, O'Keefe GE: Is hypothermia in the victim of major trauma protective or harmful? A randomized, prospective study. Ann Surg 1997; 226: 439–49.
6. Eddy VA, Morris JA Jr, Cullinane DC: Hypothermia, coagulopathy and acidosis. Surg Clin North Am 2000; 80: 845–54.
7. Garcia GD, Modesto VL, Lee KT: Avoiding hypothermia in trauma: use of the flawless heater pack, meal ready to eat, as a field-expedient means of warming crystalloid fluid. Milit Med 2000; 165: 903–4.
8. Cherry MS, Hodgson GH, Nottebrock H: Comparison of two in-line blood warmers. Can Anaesth Soc J 1981; 28: 180–1.
9. Jurkovich GJ, Greiser WB, Luterman A, et al: Hypothermia in trauma patients: an ominous predictor of survival. J Trauma 1987; 27: 1019–24.
10. Fildes J, Fisher S, Sheaff CM, Barrett JA: Effects of short heat exposure on human red and white blood cells. J Trauma 1998; 45: 479–84.
11. Reilly TM: Helping halt hypothermia: an overview of in-line blood/solution warmers. Today's Surg Nurse 1997; 19: 22–7.
12. Schwaitzberg SD, Allen MJ, Connolly RJ, Grabowy RS, Carr KL, Cleveland RJ: Rapid in-line blood warming using microwave energy: preliminary studies. J Invest Surg 1991; 4: 404–10.
13. Presson RG Jr, Bezruczko AP, Hillier SC, et al: Evaluation of a new fluid warmer: effective at low to moderate flow rates. Anesthesiology 1993; 78: 974–80.
14. Nolan JP, Dow AAC: The Level 1 fluid warmer. Anaesthesia 1991; 46: 318–19.
15. Handrigan MT, Wright RO, Becker BM, et al: Factors and methodology in achieving ideal delivery temperatures for intravenous and lavage fluid in hypothermia. Am J Emerg Med 1997; 15: 350–3.
16. Russell WJ: A review of blood warmers for massive transfusion. Anaesth Intensive Care 1974; 2: 109–30.
17. Smith CE, Kabbara A, Kramer RP, Gill I: Evaluation of a new IV fluid and blood warming system to prevent air embolism. Trauma Care J 2001; 11: 22–6.
18. Comunale ME: Risk management considerations in surgical fluid management: the prevention of hypothermia and new advances in fluid warming technology. Today's Ther Trends 2000; 18: 87–95.
19. Browne DA, De Boeck R, Morgan M: An evaluation of the Level 1 blood warmer series. Anaesthesia 1990; 45: 960–3.
20. Faries G, Johnston C, Pruitt KM, Plouff RT: Temperature relationship to distance and flow rate of warmed IV fluids. Lab Invest 1991; 20: 1198–1200.
21. Anonymous: In-line blood/solution warmers. Health Devices 1996; 25: 362–90.
22. Herron DM, Grabowy R, Connolly R, Schwaitzberg SD: The limit of bloodwarming: maximally heating blood with an inline microwave warmer. J Trauma 1997; 43: 219–28.

Questions, Anyone?

Have questions about federal government programs, benefits, and services? Get the answers you can trust from the Federal Consumer Information Center. We'll answer your questions directly or get you to the person who can.

Call toll-free **1-800-FED-INFO** (that's 1-800-333-4636) Monday-Friday 8 a.m. to 8 p.m. Eastern Time or visit **www.pueblo.gsa.gov/call**.

A public service of this publication and the U.S. General Services Administration's Federal Consumer Information Center

Copyright of Military Medicine is the property of Association of Military Surgeons of the United States and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.